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Environmental sustainability of liquid food packaging: Is there a gap between Danish consumers' perception and learnings from life cycle assessment?

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Abstract

The environmental impact of packaging has already been studied since the early development of the life cycle assessment (LCA) methodology, and today an extensive amount of studies exists. LCAs inform policy makers and guide companies in developing more environmentally sustainable packaging. From both a policy and a business perspective it is also relevant to understand what citizens and consumers recognize as being an environmentally sustainable packaging. Does perceived environmental sustainability align with the results of LCAs? And if not, where do consumers go wrong?

In this study, we investigate how well-educated young consumers living in Denmark understand the environmental sustainability of five different kinds of packaging for liquid food (milk, beer, soft drink, olive oil and skinned tomatoes) based on an on-line survey and qualitative interviews. The results are compared with a streamlined LCA we performed for packaging of beer and soft drinks, and they are validated by means of comparative LCAs of these five product categories published in scientific literature.

The results of the consumer research show that consumers assess the environmental sustainability of the tested types of packaging primarily based on the material type and on what they can personally do at the disposal stage. The consumers covered in this study do, in general, not consider the impacts of production and of transport. Amongst the investigated packaging types, bio-based types and glass are perceived as the most environmentally sustainable ones, and plastic in general is perceived least favourable. Laminated cartons receive a mixed perception. LCA results show that plastic – and especially laminated cartons – can be environmentally preferable solutions, even though they may be difficult to recycle. Our streamlined LCA on beer and soft drink shows that there is a significant difference in environmental performance between one-way glass and refillable glass, but consumers seem not to be aware of this difference. Our findings show i) that there is a gap between Danish consumers' perception of environmental sustainability of packaging and LCA results, and ii) that consumers have limited knowledge of sustainability-related eco-labels. In order to close these gaps, actions are needed both from producers, retailers and policy makers. The final aim of such improvement efforts should be to give to the consumers the possibility to make choices based on better information.

Keywords

Beverage containers; consumer research; eco-labels; circular economy; survey; qualitative interviews

1 Introduction

1.1 Packaging waste and environmental sustainability of food and beverage packaging

The frequency of purchases combined with high production volumes of consumer products mean that consumers buy large amounts of packaging, estimated as 207 million tonnes globally with a value of 384 billion USD each year (EMF, 2013). Global packaging production is expected to increase significantly in the near future, as a consequence of both demographic and macroeconomic trends. By 2030, three billion new consumers are expected to enter the global middle class, equal to a 160% increase compared to 2009 (OECD, 2011). These consumers will consume more in general, and they will switch from buying loose, unbranded products (such as groceries at the local market) to buying manufactured, packaged goods. According to estimates by the Ellen MacArthur Foundation (EMF), this will lead to a 47% increase in packaging (by weight) in emerging markets by 2025 compared to 2012 (EMF, 2013).

From a societal point of view, the role of packaging is controversial. Food packaging can enable safe and efficient supply of products and minimise the environmental impacts of producing, transporting, using and disposing of food products (Verghese et al., 2012). On the other hand, packaging in general is a major contributor to municipal solid waste (MSW), representing around 31 wt.% of MSW at the European level (EEA, 2013). In the context of the EU Action Plan for Circular Economy released at the end of 2015 (EC, 2015), new ambitious goals for material recycling rates have been set. According to the new legislative rules amending Directive 94/62/EC on packaging and packaging waste approved on by EU Member states on May 2018 "*no later than 31 December 2025 a minimum of 65 % by weight of all packaging waste will be recycled*" (European Union, 2018). The different packaging materials (including food packaging) have very different recycling rates, e.g. in Denmark in 2012 almost all glass was recycled (97.7%wt.), meanwhile only 29.4% of plastic packaging had a second life with the rest mainly sent to incineration with energy recovery (Miljøstyrelsen, 2015). For paper and metal, the recycling rates were 76.5% and 51.8%, respectively. According to the Danish Environmental Protection Agency, 895,000 tons of packaging material were used in 2012 in Denmark, which equals 160 kg per person (Miljøstyrelsen, 2015).

The increase in the amount of packaging consumed and the policy targets on recycling have been putting pressure on companies to take action. For the food and beverage industry, environmental sustainability has become a key target, and Life Cycle Assessment (LCA) has emerged as a leading method for evaluating the overall environmental impact of products (Svanes et al., 2010). The very first LCA studies were performed on beverage packaging (Hunt and Franklin, 1996), and throughout the years, LCA proved to be a highly valuable decision support tool in driving more environmentally preferable food and beverage packaging solutions (UNEP & SETAC, 2013). However, performing a full LCA is time- and resource-consuming, therefore streamlined LCA methods and tools have spread in the sector (Niero et al., 2016; Speck et al., 2015; Verghese et al., 2010).

1.2 Consumer perception of packaging

Even though packaging can have a positive environmental effect, as it prolongs the lifetime of products and prevents food waste, consumers tend to think of food and beverage packaging as something negative (WRAP, 2013). Many studies have been performed on consumers´ perception of packaging, e.g. Ampuero and Vila (2006), Gelici-Zeko et al. (2013), but only few have looked at the environmental sustainability perception of food and beverage packaging. The first investigation of consumers´ environmental perception of beverage containers was conducted by Van Dam & van Trijp (1994). They concluded that Dutch consumers perceived glass packaging and, to a lesser extent, paper packaging as environmentally friendly, whereas tin, plastic and carton containers were perceived as the least sustainable options. This picture was confirmed in a later study by van Dam (1996), who investigated the product characteristics that constitute the perceived sustainability (e.g. material type, size) and concluded that consumers judge environmental sustainability mainly based on material type and possibility of re-use. More recently, Lindh et al. (2015) conducted a study among Swedish consumers, confirming that consumers' environmental perception of food packaging is mainly grounded in material considerations. Their main findings are that paper-based packaging is perceived as the most sustainable and plastic and metal as the least ones. Korhonen et al. (2015) performed a wide, cross-continental study among University students in Europe, Latin America, North America, and Asia on attitudes towards packaging and perception of packaging materials on several aspects, including sustainability. The study revealed that paper and carton are perceived as the most pro-environmental materials. Moreover, cultural differences among countries emerged, especially for the perception of plastics, aluminium and tin: in countries with developed recycling systems, such as Denmark, pro-environmental packaging was perceived as recyclable or made of recycled content (Korhonen et al., 2015).

Martinho et al. (2015) investigated the factors that influence consumers' product purchasing and recycling behaviour with respect to sustainable packaging and found that gender, environmental awareness, concerns about societal opinions, positive attitude towards green purchasing, and the perception of consumer actions are the differentiating elements. Environmental labels, or eco-labels, represent a major tool for communicating the environmental performance of products, but there are studies indicating that knowledge of eco-labels is very limited among consumers, e.g. Gadema and Oglethorpe (2011), Hartikainen et al. (2014), Zhao et al. (2018). Such lack of knowledge could be explained by the exponential growth of the number of eco-labels over the recent years (Janßen and Langen, 2017).

1.3 Aim of the study

To our knowledge, only one previous study (Steenis et al., 2017) has compared the perceived environmental sustainability of food packaging (namely tomato soup) with the scientifically assessed environmental sustainability performances quantified through LCA. However, such knowledge on what consumers perceive as environmentally sustainable as well as on their understanding of product labels is a key enabler for strategic decision making in the context of circular economy, both for sustainable packaging design and for green purchase strategies. This study addresses a specific and broader category of food packaging, namely liquid food packaging. For beverages and liquid food more generally indeed the necessity of packaging cannot be questioned by consumers. Moreover, the relative environmental impact of the packaging compared to the content is much higher for beverages and liquid food products than for

other types of food. For instance for soft drinks, packaging accounts for more than 50% of the overall carbon footprint compared to 10% for food in general (INCPEN, 2009).

We conducted an exploratory study with a twofold aim: (i) to investigate how consumers living in Denmark perceive the environmental sustainability of liquid food packaging and how much they know about eco-labels and (ii) to compare the perceived environmental sustainability with actual LCA results on the matter. Therefore, we formulated the following research questions (RQs):

RQ1: How do Danish consumers perceive the environmental sustainability of liquid food packaging?

RQ2: To what extent do Danish consumers know the meaning of eco-labels on packaging?

RQ3: How does the perception of Danish consumers with regard to the environmental sustainability of liquid food packaging compare with what can be concluded from quantitative assessments using LCA?

2 Materials and methods

The research design was structured in two parts, adopting both quantitative and qualitative methods for the consumer research part and quantitative methods for the environmental sustainability assessment, as represented in Figure 1, which shows the linkage with research questions (RQ1-3). The analysis of the perception and knowledge of Danish consumers has been performed through an on-line survey and qualitative interviews (section 2.1). The assessment of the environmental sustainability of liquid food packaging was performed through quantification of the potential environmental impacts of a selection of packaging by means of a streamlined LCA tool (section 2.2), complemented with the findings from a literature review of published LCA studies in the field (section 2.3). A procedure to compare the results from consumer research and LCA has been developed and implemented (section 2.4).

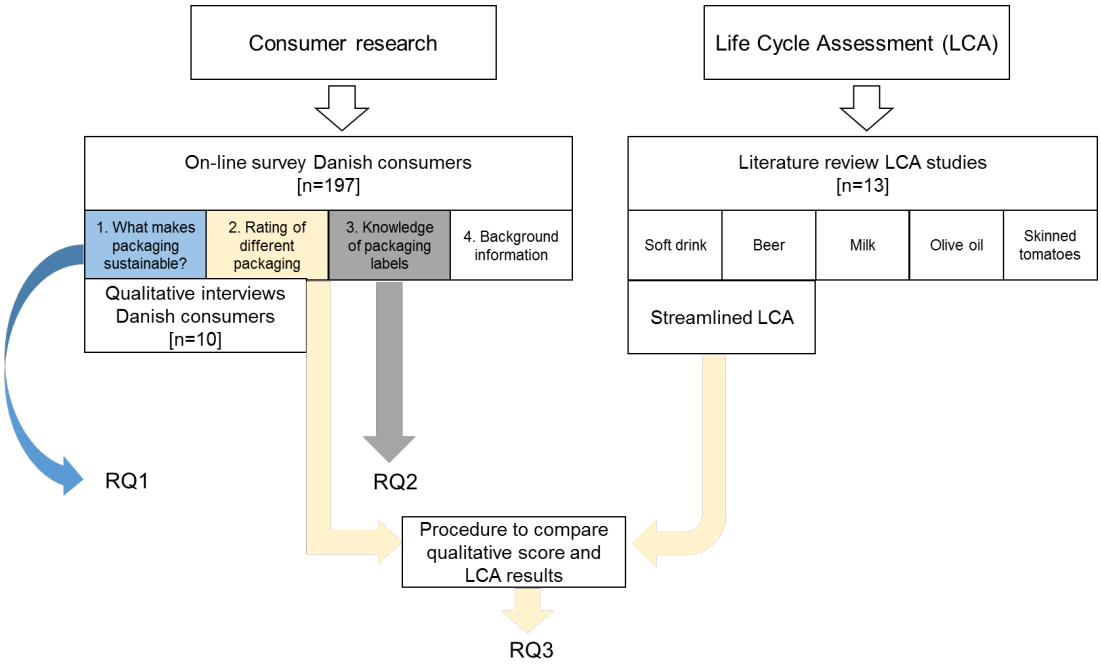

Figure 1. Structure of the research design with regard to consumer research and quantitative environmental sustainability assessment, i.e. Life Cycle Assessment (LCA), of liquid food packaging and link with research questions (RQ1-3).

2.1 Investigation of consumers´ perception

The use of on-line surveys and qualitative interviews is well established to collect empirical data in the field of consumer behaviour (Lemke and Luzio, 2014; Lindh et al., 2015; Martinho et al., 2015). Both methods were used in the present study to investigate how consumers reason when it comes to environmental sustainability of liquid food packaging and how different liquid beverage packaging alternatives are perceived (RQ1). Five different product categories of liquid food were considered: soft drink, beer, milk, olive oil and skinned tomatoes. The packaging alternatives investigated for each product category are reported in Figure 2.

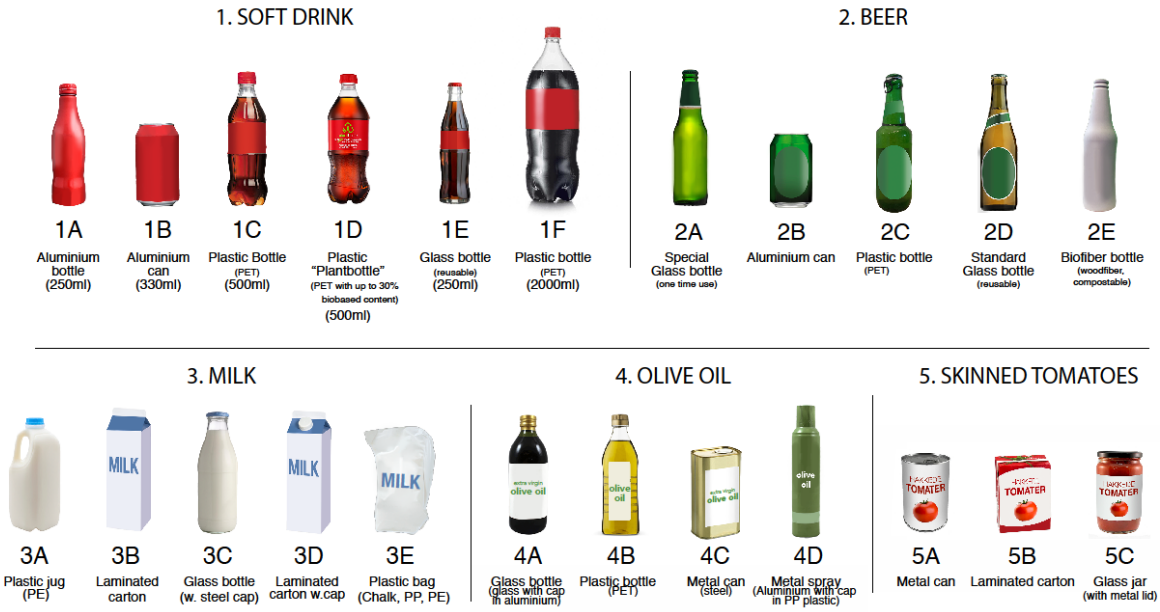

Figure 2. Overview of the 23 different packaging alternatives tested in the on-line survey for the five product categories: 1) soft drinks, 2) beer, 3) milk, 4) olive oil and 5) skinned tomatoes; PET = Polyethylene Terephthalate, PE = Polyethylene, PP = Polypropylene.

The consumer target group was young well-educated people living in Denmark, reached through social media and internet fora, as reported in Boesen (2016). The on-line survey was answered by 197 Danish consumers during December 2015. It is reported in section A of the Supplementary Material and was structured in four main sections. The first section (see section A.1 in the Supplementary Material) includes a list of general questions on consumers´ attitudes towards sustainability, their largest environmental concern regarding packaging, packaging attributes that make packaging sustainable, and finally a series of statements related to packaging and packaging environmental sustainability where the respondent had to indicate the level of agreement. Some of the questions (see section A.1 of the Supplementary Material, sub-section 1.4) were taken from the research performed by Korhonen et al. (2015). In the second section (see section A.2 in the Supplementary Material) the pictures of alternative packaging containing the same liquid food product were reported (see Figure 2) for each product category, and the respondents were asked to indicate how sustainable they perceive the alternatives on a 1-5 scale, where 1=very unsustainable

and 5=very sustainable. In the third section of the survey, the knowledge about a selection of product labels related to sustainability was tested in order to answer RQ2. The labels shown represent a sample of eco-labels that are available on packaging and address a relevant feature of packaging in a circular economy, i.e. recyclability, compostability, and sourcing of raw materials, see Table S1 in the Supplementary Material for a description. The respondents had to select among different plausible meanings, as reported in section A.3 in the Supplementary Material. In the last section, background information was asked for contextual information such as age, gender, education, possibility of sorting waste, etc. (see section A.4 in the Supplementary Material).

In order to validate the findings of the on-line survey and to get a better understanding of the reasoning behind the sustainability rating, a total of 10 in-depth semi-structured interviews (25-40 minutes) were conducted with consumers (age 22-31) with various educational backgrounds, housing situations and genders. The questions were open ended, to give the consumer the opportunity to answer freely. It is indeed argued by van Dam & van Trijp (1994) and Lindh et al., (2015) that this is a good way to investigate consumer perception. A semi-structured interview guideline was used, encompassing the use of two visual exercises (see section B1 of the Supplementary Material for the interview guide), which is in line with similar types of exploratory ecological research (Lemke and Luzio, 2014). The two visual exercises were conducted to capture the respondents' opinions visually and served as a conversation tool to guide the discussion. In the first visual exercise (named "environmental issue matrix") the respondents were asked to prioritize eight environmental issues related to packaging, with six of these directly taken from relevant impact categories considered in LCA and two complementary issues, i.e. visual pollution from waste in nature and harm to animal and fish life, e.g. from plastic in the oceans. In the second visual exercise (named "packaging sustainability prioritisation line") the respondents had to prioritize the packaging alternatives from the survey according to their perceived level of sustainability. All interviews were recorded and pictures were taken of the results of the visual exercises. The pictures and recordings were later used to document each interview (see section B.2. for a summary of qualitative interviews). In this process, interesting points were written down on post-its and these were later clustered and analysed in an analytic pattern recognition process (Noblit and Hare, 1988).

2.2 Streamlined LCA for beer and soft drink

We used a customized software used by industry for packaging life cycle assessment, i.e. Instant LCA Packaging™ provided by RDC Environment, which has already been used to perform LCA on beverage packaging (Niero et al., 2016; Niero and Kalbar, 2019). The software follows the ISO 14040 standard, building on the ecoinvent v2.2 database (Frischknecht et al., 2007). The features of the software allowed performing comparative LCAs of two product categories, namely beer and soft drink.

The chosen functional unit is the "containment of 1 hl of beverage". In terms of system boundaries, the production of the content (i.e. beer and soft drink) and the use phase (e.g. refrigeration) were excluded. The main values and assumptions considered for the two product categories are reported in Table 1. The end-of-life (EoL) scenario was modelled based on official return rates for refund bottles in Denmark (Dansk Retursystem, 2015). All beer and soft drink packaging types were assumed to be part of the national refund system. According to Dansk Retursystem (2015) 89%wt. of single-use packaging (aluminium cans, PET-bottles and one-way glass bottles) was recycled, and 98%wt. of refillable standard glass bottles were reused. It was not possible to obtain information of cans and PET bottles separately, so a value of recycling

rate of 89% was assumed for both. For the disposed packaging it was considered that 98% is incinerated with energy recovery and 2% goes to landfill. The EoL modelling was performed in accordance with the EoL formula provided by the Product Environmental Footprint (PEF) guide (EC, 2013). In the soft drink category, aluminium cans, PET bottles and one-way glass bottles are assumed to be recycled, meanwhile the "standard" glass bottles are assumed to be reused. When the plastic beer bottle was on the Danish market in the mid-/end- 1990s it was reused, which was not known when the survey was made and thus it was not stated in the description. Therefore, both a recycling and a reuse scenario were modelled for the plastic bottle. In the latter, a return rate of 89%wt. was assumed.

The life cycle impact assessment (LCIA) was performed using the ILCD 2011 recommended methodology (Hauschild et al., 2013), as embedded in the Instant LCA Packaging™ v1.12.1. The impact categories covered include global warming potential, abiotic resource depletion potential, acidification potential, freshwater, marine and terrestrial eutrophication potentials, photochemical oxidant formation potential, stratospheric ozone depletion potential, human toxicity potential (including both carcinogenic effects and non-carcinogenic effects) and freshwater eco-toxicity potential, particulate matter/respiratory inorganics potential, ionizing radiation potential impacting human health, land use potential. For water use, the indicator considered refers to the scarcity-adjusted mass of water, i.e. water consumption.

Table 1. List of main input data and assumptions considered in the Instant LCA Packaging™ for the packaging alternatives considered for soft drink and beer. Abbreviations on materials: Al= aluminium, PET = Polyethylene Terephthalate, LDPE = Low Density Polyethylene, HDPE = High Density Polyethylene. Note: Options 1A-Alu bottle, 1D-Plant bottle and 2E–Bio-fiber bottle were not modelled, due to lack of data and are thus marked with grey background.

Beverage	**1. SOFT DRINK**							**2. BEER**			
Packaging	1A – Al bottle	1B – Al can	1C – Plastic PET bottle (50 cl)	1D – Plant-bottle	1E - Refillable Glass bottle	1F – Plastic PET bottle (200 cml)	2A – Single use glass bottle	2B – Al can	2C - Plastic PET bottle	2D - Refillable glass bottle	2E – Bio-fiber bottle
Content [cl]	33	33	50	50	25	200	33	33	33	33	33
Weight bottle [g/bottle]	n.a.	12.7 (body)[a] 2.9 (end)[a]	24 [c]	n.a.	393 [c]	43 [c]	240[c]	12.7 (body)[b] 2.9 (end)[b]	38[c]	301[c]	n.a.
Recycled content	n.a.	67.8%[b]	0%	n.a.	75.4%[d]	0%	75.4% [d]	67.8%[b]	0%	75.4%[d]	n.a.
Weight cap [g/bottle] (material)	n.a.	-	1.1 (Al) 0.25 (HDPE) 0.33 (LDPE)	n.a.	0.19 (LDPE) 2 (steel)	3 (HDPE)	0.19 (LDPE) 2 (steel)	-	1.1 (Al) 0.25 (HDPE) 0.33 (LDPE)	0.19 (LDPE) 2 (steel)	n.a.

[a] Source: (Detzel and Mönckert, 2009)
[b] Source: (PE Americas, 2010)
[c] Authors' own measurements
[d] Source: (Vieitez et al., 2011)

2.3 Literature review on LCA of liquid food packaging

A literature review was conducted for the five selected product categories investigated in the study, in order to assess the environmental impacts of different packaging alternatives within each product category. Data were collected in December 2015 from DTU Findit, i.e. the online library service of the

Technical University of Denmark, covering 190 million articles from scientific journals and subject databases and 150,000 e-books. The details on the literature review are reported in Section C (Table S2) of the Supplementary Material.

2.4 Procedure for comparing LCA results with perception scores

In order to compare the LCA results with the perception scores, we followed a 2-steps procedure. First, to illustrate the differences observed between the different packaging types for each impact category, we performed internal normalization, with the primary objective to eliminate the specificity of the impact indicator units. The reference system chosen is the maximum within each impact category, i.e. the so-called 'division-by-maximum' internal normalization (Laurent and Hauschild, 2015). We considered the global warming potential (GWP) as proxy indicator for environmental sustainability, as it has proven to be a good predictor for other impact categories in the case of packaging (Amienyo et al., 2013; Niero et al., 2016; Scipioni et al., 2013). However, caution should be used in using GWP as a stand-alone indicator of environmental sustainability, e.g. in the case of energy where the environmental impacts may not be led by fossil fuels consumption (Laurent et al., 2012) or for urban consumption patterns (Kalbar et al., 2017). Second, the qualitative scores in the 1-5 scale obtained from the survey were inversed and converted to % values, so that a higher score would represent a higher environmental impact, in order to be comparable to the LCA results and therefore provide an answer to RQ3.

3 Results

The results section is divided in two main parts. Section 3.1 summarizes the findings of the empirical study on consumer perception analysis, providing the answers to RQ1 (section 3.1.1) and RQ2 (section 3.1.2). Section 3.2 presents the findings of the quantitative environmental sustainability assessment part, namely the results of the streamlined LCA for beer and soft drink (section 3.2.1), the outcomes of the literature review on LCA of the five categories of liquid food packaging considered in the study (section 3.2.2), and the answer to RQ3 (section 3.2.3).

3.1 Findings from empirical study on consumer research

Respondents were 62% women, with an average age of 29.7 years and were longer educated than the national average in Denmark, with a majority having either a Bachelor or a Master degree, as reported in Table 2.

Table 2: Educational level of the respondents to the survey and comparison with average Danish population and population in the age interval 25-35.

Educational level (highest finished or current)	Survey (total n=197)		Danish average[a]	Danish average (age 25-35) [a]
	n	%	%	%
Secondary school	1	0.5	20.0	18
High school or equivalent	8	4.1	5.5	10
Vocational / technical school	11	5.6	36.0	30
Professional degree	7	3.6	4.7	5
Bachelor degree	82	41.8	18.6	23
Master degree	78	39.8	9.2	13
PhD degree	9	4.6	0.7	0.42

[a] *Source: Statistics Denmark (2015)*

3.1.1. How do Danish consumers perceive the environmental sustainability of liquid food packaging?

Results on what makes packaging sustainable according to the surveyed consumers are reported in Figure 3. It emerges that the most frequent features chosen by the survey respondents are: recyclability ("*packaging material can be recycled*", 79%), compostability/biodegradability ("*package is compostable/biodegradable*", 76%) and recycled content ("*package is made from recycled material*", 73%). It is worth to note that even though the majority find recyclability important, only 9% of the respondents chose the option that packaging should consist of a single material, which in many cases is prerequisite for (feasible) recyclability. Moreover, only 3% of respondents selected the option that the packaging should "*consist of small portion sizes*", which could indicate that consumers do not see a link between food waste and packaging size. For reference, Figure 3 also reports the findings by Korhonen et al. (2015), although the results of the two studies are not fully comparable, since the consumers were not given all the same options, and the wordings of the options were slightly different.

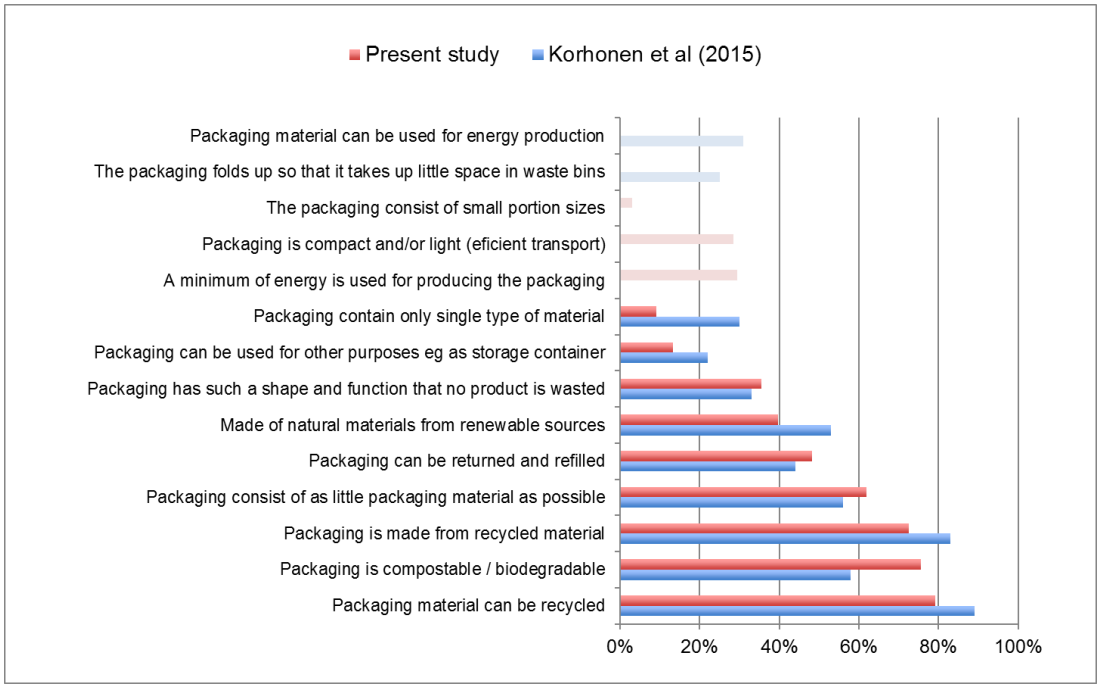

Figure 3 Results from on-line survey on what makes packaging sustainable according to the investigated consumers. Results from Korhonen et al., (2015) are also reported, as term of reference. Note: The five upper-most answer options are shown in light colours since they only existed in one of the studies.

Two main characteristics of environmental sustainability were repeatedly mentioned also by participants to the interviews: the recyclability and the "naturalness" of the material. The latter was motivated by the intention to avoid negative consequences of packaging waste in nature, e.g. as said by one interviewee that "*what makes packaging sustainable is that it is easily degradable if it should end up in nature…not like plastic that can be in nature for thousands of years*".

Figure 4 summarizes the distribution of consumers' scores of packaging sustainability for the five liquid food packaging categories considered.

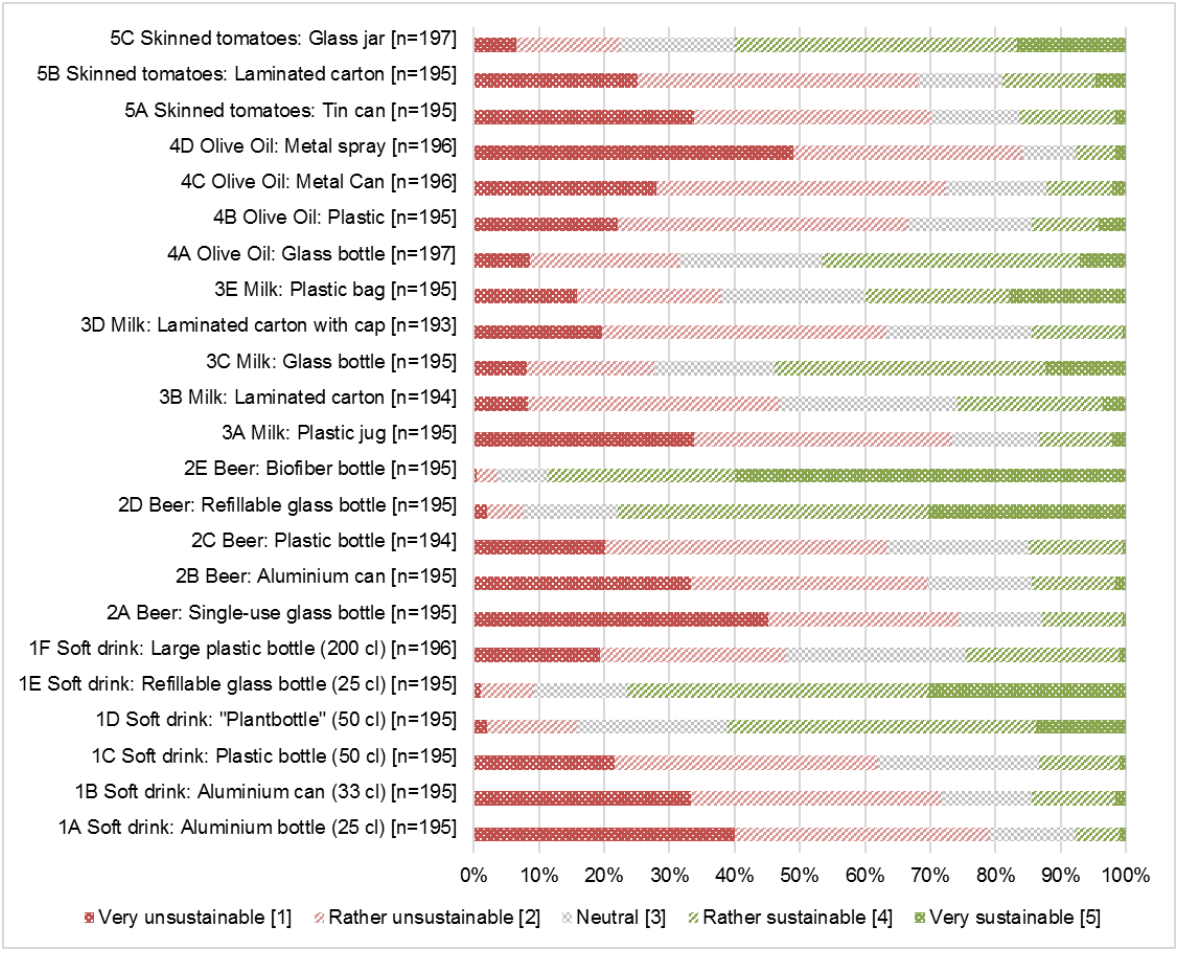

Figure 4. Distribution of consumers' scores of packaging environmental sustainability for the five liquid food packaging categories considered (soft drink, beer, milk, olive oil, skinned tomatoes) with indication of number of respondents.

For skinned tomatoes, the glass jar was perceived to be the most sustainable option by the majority of respondents, meanwhile the laminated carton and the tin can were overall perceived as unsustainable. In the qualitative interviews, glass performed as the best alternative (in 6 out of 10 interviews), and the primary reason given by the respondents was its recyclability, as "*glass can be melted down and be reused*". One respondent mentioned that glass jars can be reused for other purposes: "*I reuse my jars a lot and they stay quite a long time. I don´t really throw them away as I use them for spices and nuts*". Another respondent with a high environmental concern had the argument that it was most likely, that others (less environmentally concerned) would recycle glass, but not the tin can. The perception of the laminated carton was more balanced (best option in 4 cases and worst option in 5 cases): one respondent found it sustainable because "*it is made of paper, so it must be good*", while others found it as the least sustainable "*due to the aluminium foil, so you can´t sort it*".

In the milk product category, the same tendency is seen as for the canned tomatoes, with glass found to be the best-perceived solution by the majority of respondents. The plain laminated carton and the plastic jug were scored as either very unsustainable or rather unsustainable by the majority of respondents. The results from the qualitative interviews confirmed the survey results: glass was seen as a sustainable and attractive solution (best option in 3 out of 10 interviews), even though some interviewees found it as the

least sustainable cause "*you have to sort the metal lid*". One interviewee pointed out that glass is sustainable "*as it can be washed and reused again and again*", meanwhile another stated that "*when you melt it, it pollutes a lot*". This indicated that there is no clear understanding among interviewees about the different options connected with the end-of-life options for glass. With regard to the plastic jug, some found it sustainable ("*you save materials, so I think its sustainability is high*"), meanwhile others had contrasting opinion ("*I think it is not very sustainable because I think that plastic is not so sustainable*"). The plain carton with cap scored always worse than the one without cap, due to the combination of two materials.

A similar pattern was also found for olive oil: glass emerged as the most sustainable option in around half of the cases. The metal spray was assessed as overall unsustainable by around 80% of the respondents with half of them marking it as "very unsustainable". The metal can and the plastic bottle were considered unsustainable by ca 70% of the consumers investigated. Most of the respondents from the qualitative interviews (6 out of 10) identified the glass bottle as the most sustainable and assumed that it would be reused, and not re-melted. One interviewee acknowledged that "*the plastic is lighter and thereby more sustainable than the glass option*". There was agreement that the spray can was unsustainable due to its mixed materials composition, but for the rest of the packaging types the respondents varied in their reasoning.

In the beer category, the respondents had to choose between five alternatives, and here two options outperformed the rest: the well-known refillable glass bottle and the innovative bio-fiber bottle under development (https://carlsberggroup.com/newsroom/carlsberg-unveils-new-green-fiber-bottle-design/). Both were scored as overall sustainable by more than two thirds of the sample. The PET bottle, aluminium can and single-use glass bottle were scored as overall unsustainable by the majority of respondents. This ranking was confirmed in the qualitative interviews, where no respondent questioned the sustainability of the bio-fiber bottle or the claim of biodegradability, meanwhile several people mentioned concerns of the environmental impact of lost bottle caps. The refillable glass bottle ranked as the second most sustainable option in 8 out of 10 cases.

The results for the soft drink category were aligned with the results from the beer category with the reusable glass packaging perceived as sustainable solution by almost 80% of the respondents. The so-called Plant Bottle with up to 30% bio-based plastics was perceived as sustainable by the majority of the consumers interviewed. Aluminium bottle and aluminium can were perceived as "very unsustainable" by one third of respondents and overall as unsustainable by the high majority, meanwhile an overall negative score was given to the plastic bottles (200 cl and 50 cl). This was the only category where the sizes of the packaging differed and this choice was done with the aim to investigate whether people consider larger packages to be more sustainable. This proved to be the case, but only to a limited extent. The large 200 cl PET bottle scored slightly better than the 50 cl version, and the smaller 25 cl aluminium bottle scored a bit lower than the 33 cl aluminium can. In the survey, it was not stated explicitly whether the respondents should judge the sustainability per packaging or per content, which might be the reason of the limited numbers of comments regarding size. In the qualitative interviews, the respondents were asked directly to make their assessment "per litre of beverage" and this is probably the reason why the 200 cl bottle was perceived more environmentally sustainable than the 50 cl bottle size. The packaging types that were found among the first three sustainable options are the plant bottle (in 8 out of 10 cases) the 200 cl PET

bottle (in 7 out of 10 cases), and the glass bottle (in 5 out of 10 cases). Only one respondent questioned the claim of "up to 30% bio-based materials" for the plant bottle. All other respondents were positive and some even expressed that they expected that such a packaging would also be biodegradable.

Summarizing the information on the least and most sustainable materials according to the consumers included in the sample, it can be concluded that bio-material-based packaging types and glass packaging are perceived as the most sustainable options, traditional fossil-based plastic is perceived negatively, meanwhile laminated cartons receive a mixed perception. However, it is interesting to note that almost no respondents thought that laminated carton was the most sustainable option. In accordance with Korhonen et al. (2015), glass is perceived both as the most environmentally sustainable option (when considering the refillable glass bottle) and as the least environmentally sustainable option (when the one-way glass bottle is taken into account).

3.1.2 To what extent do Danish consumers know about the meaning of eco-labels on packaging?

The percentage of correct answers for the seven different labels (Green Dot, Universal Recycling Symbol, Resin Identification Codes, Seedling® compostable label, Forest Stewardship Council (FSC) label, Cradle to cradle® certification label, Pitch-in Symbol/Don't litter) can be seen in Table 3. It should be noted that these percentages are the result of a multiple choice test format, i.e. with pre-defined answer options, and if free text questions had been used instead, the percentages of correct answers would likely have been lower.

Table 3 Percentage of the respondents providing the correct answer/not knowing the meaning of the eco-labels for packaging during a multiple choice test. The full details of all responses are reported in section A.5 of the Supplementary information.

Label	Name	Correct answer	Do not know
	The Green Dot	6.1%	11.7%
	Universal Recycling Symbol	51.0%	6.6%
	Resin Identification Codes	22.4%	39.3%
	Seedling® compostable label	32.7%	43.4%
	Forest Stewardship Council (FSC) label	72.4%	12.2%
	Cradle to cradle® certification label	50%	29.6%
	PITCH-IN Symbol (Don't litter)	43.9%	4.1%

It can be concluded that the general knowledge of eco-labels varies and is quite limited for most of the tested labels addressing circular features. Only 6% of the respondents knew the meaning of the wide-

spread Green Dot Logo, meanwhile the large majority of users confused it with the recycling symbol, correctly identified by around half of the respondents. 24% of consumers surveyed knew the meaning of the polymer resin identification codes and indeed a low familiarity was expected in this category, since such codes are primarily aimed at recycling facilities and not at consumers. It is interesting to note that the majority of users (72%) knew the correct meaning of the FSC label, which may be explained considering that the label is used not only on packaging, but also on many products made from wood. It is more surprising that half of the respondents knew the meaning of the cradle-to-cradle (C2C) certification label, as only few certified packaging types exist on the Danish market. The reason is probably due to the fact that many design engineers were among the respondents and the C2C design framework is well known among this group of individuals. Lastly, around a third of the respondents knew the meaning of the relatively new seedling label for compostability, which was unexpectedly high. It is also worth noting that the percentage of respondents stating they do not know the meaning of the symbol varies between 4% (in the case of the "don´t litter" label) and 43% (in the case of the seedling label for compostability).

3.2 Findings from Life Cycle Assessment

3.2.1 Results from streamlined LCA

The results of the streamlined LCA for soft drink and beer packaging alternatives are reported in Table 4. The packaging type with the best performance for beer is the refillable glass bottle, which has the lowest scores in all 14 impact categories considered. For all impact categories, except stratospheric ozone depletion and ionizing radiation, the packaging with highest potential environmental impacts is the one-way glass bottle. Based on the LCIA results, it can be concluded that the PET bottle and the aluminium can have the same environmental sustainability performances. Because the bio-fiber bottle is still under development and data were not available, it was not possible to perform the LCA.

In the case of soft drinks, the LCA calculations showed that except for stratospheric ozone depletion the PET bottle is the best option, and that increased container size clearly has a positive effect. It was not possible to directly assess the plant bottle due to lack of data, as well as the aluminium bottle, which is not included as an option in the software used. In most impact categories the 50 cl PET bottle showed a comparable performance as the 25 cl reusable glass bottle, and the aluminium can scored least preferable.

Table 4. Life Cycle Impact Assessment (LCIA) scores per functional unit (FU) for the packaging alternatives modelled in the streamlined LCA in the case of soft drinks and beer. Abbreviations on materials: PET = Polyethylene Terephthalate.

Beverage	1. Soft drink					2. Beer		
Impact Categories	**1B Aluminium can (33 cl)**	**1C Plastic PET bottle (50 cl)**	**1E Reusable glass bottle (25 cl)**	**1F Plastic PET bottle (200 cl)**	**2A Single use glass bottle (33 cl)**	**2B Aluminium can (33 cl)**	**2C Plastic PET Bottle (33c cl)**	**2D Reusable glass bottle (33 cl)**
Global Warming Potential (kg CO_2 eq / FU)	51.450	23.018	25.025	11.435	96.255	51.450	46.343	14.144
Abiotic resource depletion (kg Sb eq / FU)	0.003	0.001	0.003	0.000	0.003	0.003	0.002	0.002
Acidification (mol H+ eq / FU)	0.275	0.090	0.118	0.047	0.599	0.275	0.175	0.075
Freshwater eutrophication (kg P eq / FU)	0.001	0.001	0.001	0.000	0.003	0.001	0.001	0.000
Marine eutrophication (kg N eq / FU)	0.049	0.025	0.031	0.014	0.119	0.049	0.048	0.018
Terrestrial eutrophication (kmol N eq / FU)	0.533	0.273	0.348	0.150	1.531	0.533	0.527	0.204
Photochemical oxidant formation (kg NMVOC eq/ FU)	0.138	0.070	0.068	0.034	0.319	0.138	0.141	0.035
Stratospheric ozone depletion (kg CFC-11 eq / FU)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Water consumption (m^3 / FU)	0.620	0.130	0.282	0.074	0.849	0.620	0.249	0.223
Human toxicity (CTU / FU)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ecotoxicity (CTU / FU)	3.981	3.627	4.007	2.028	25.432	3.981	6.576	2.506
Particulate matter/Respiratory inorganics (kg PM2.5 eq / FU)	0.016	0.004	0.006	0.002	0.031	0.016	0.008	0.004
Ionising radiation (kg U235 eq / FU)	35.044	3.997	2.629	1.840	8.264	35.044	9.858	1.554
Land use (kg C eq / FU)	47.504	23.125	47.150	16.911	162.903	47.504	34.132	33.160

3.2.2 Validation with LCA results from literature on liquid food packaging

No published study on skinned tomatoes was found, therefore no conclusion can be drawn on which is the most environmentally sustainable option amongst the types investigated here.

Within the olive oil category, only one comparative study of different packaging types was retrieved from literature (Accorsi et al., 2015), which concludes that PET bottles are more environmentally sustainable than glass packaging.

In the case of milk, the LCA studies covered in the meta-analysis performed by von Falkenstein et al. (2010) indicate general trends regarding the performance of beverage cartons versus alternative packaging systems for certain environmental impact categories. For climate change, fossil resource consumption, and acidification – all regarded by the majority of all studies – beverage cartons generally have the most favourable results, while in terms of land use for forestry, they clearly require the largest area. For particulate matter and terrestrial eutrophication (covered by fewer LCA studies), the result 'pattern' points towards a favourable picture for beverage cartons (von Falkenstein et al., 2010). These results are confirmed by other studies, e.g. Meneses et al. (2012) concluded that for global warming and acidification larger aseptic carton packages with recycling as disposal scenario have the lowest environmental impact potentials compared to PET bottles and HDPE bottles. Similar results were also obtained by Scipioni et al. (2013), who compared laminated carton containers and HDPE bottles under Italian conditions, considering climate change, fossil fuels depletion, particulate matter formation, photochemical oxidant formation, and terrestrial acidification. Differing results were obtained under Chinese conditions by Xie et al. (2011), where

the laminated carton container showed to have a higher environmental impact than the polyethylene bottles, but this was mainly due to the EoL treatment assumed in that study, which excluded recycling.

For beer and soft drink packaging, the results obtained in the streamlined LCAs were confirmed by literature. Simon et al. (2015) concluded that considering the whole life cycle of packaging materials, the one-way glass and Al can had the highest global warming potential in an open-loop material scenario, while the score of the Al can in the same impact category would become smaller than that of the small PET-bottles in a closed-loop material recycling scenario. In the study of Pasqualino et al. (2011), despite the EoL options considered (landfill, incineration or recycling), the 1 l HDPE bottle turned out to have the lowest environmental impact compared to large Al can (50 cl), large glass bottle (100 cl), medium Al can (33 cl) and medium glass bottle (33 cl). According to Amienyo et al. (2013) the carbonated soft drink packaged in 200 cl PET bottles is the most environmentally sustainable option for most impact categories, including climate change, while the same drink packaged in one-way glass bottles is the worst option, in terms of environmental sustainability. However, they also find that reusing glass bottles 3 times would make the carbon footprint of the drink in glass bottles comparable to that in aluminium cans and 50 cl PET bottles.

3.2.3 How does the perception of Danish consumers with regard to the environmental sustainability of liquid food packaging compare with what can be concluded from quantitative assessments using LCA?

In general there is good consistency in what different respondents perceive across the product groups. The overall picture is that glass is regarded as the most sustainable packaging material. Plastic bottles, and metal cans are perceived negatively, and laminated carton is also perceived rather negative, though more mixed. The respondents display great faith in the sustainability of the three new packaging innovations included in the survey (milk bag, plant bottle for soft drink and bio-fiber bottle for beer). The milk bag is currently on the market and the plant bottle is not anymore, while the bio-fiber bottle is currently being developed, and therefore the consumers based their perception entirely on the picture and description provided.

Figure 5 displays the comparison between the perceived environmental impact and scientifically assessed environmental impact (represented here by Global Warming Potential, GWP) for beer and soft drink. For both product categories, the refillable glass bottle is rightfully perceived as the most environmentally sustainable. Regarding soft drinks, the respondents perceive plastic PET bottles (both 200 cl and 50 cl) with a similar environmental sustainability as aluminium cans, but the LCA results show that their GWP scores are lower than the one of aluminium cans. Consumers thus seem to underestimate the environmental sustainability of plastic bottles. For beer, there is a negative perception of aluminium cans and PET bottles (with inverse perception scores of 90% and 80%, respectively, compared with single use glass bottles which have the highest score. This is not supported by LCA results, which show that the GWP impact score of aluminium can and PET bottle is half the impact of the single use glass bottle.

Not shown in the figure are skinned tomato containers, milk and olive oil. For skinned tomato containers, no LCA studies were found. For olive oil, glass is perceived as the most environmentally sustainable option (compared to PET, metal can and spray can), but LCA results highlight the potential of PET bottles to reduce the environmental impact of olive oil supply chains, through e.g. dematerialization and reusable and recyclable PET bottles (Accorsi et al., 2015). Finally, for milk, if the glass bottle is reused then the

consumers' assessment is likely to be realistic. The one-way glass bottle would likely be the least sustainable option.

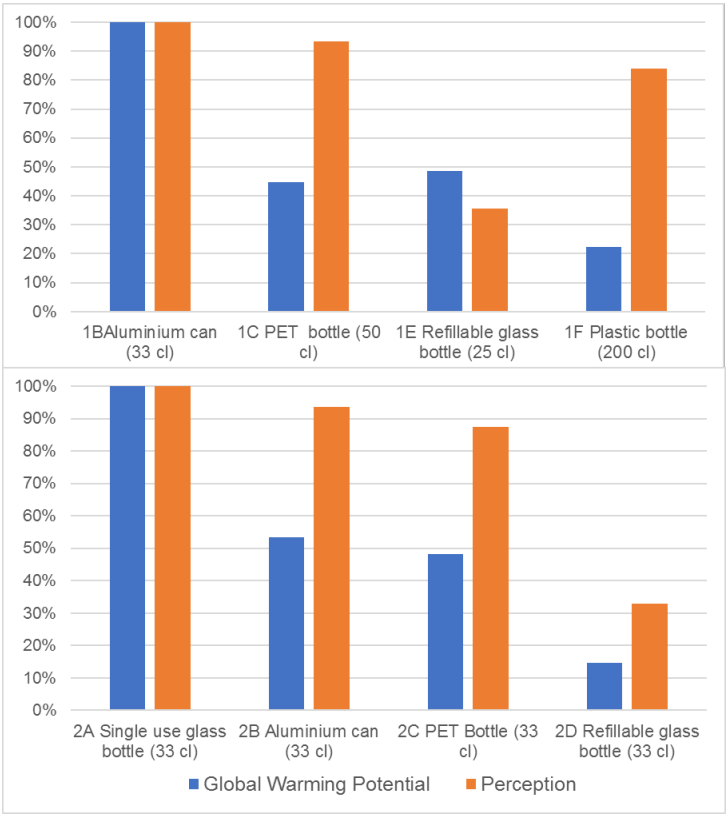

Figure 5 Comparison of perceived environmental impact (inversed perception score) and scientifically assessed environmental impact (represented here by Global Warming Potential) for 1. soft drinks (top) and 2. beer (bottom). Both scores are normalized by maximum.

4 Discussion

4.1 Theoretical implications

The present study contributes to the research agenda on sustainable consumption and production of food and beverage packaging by exploring how to bridge the gap between consumer research and LCA.

First, the study investigates how environmentally sustainable Danish consumers perceive liquid food packaging (RQ1). The presented results indicate that when it comes to packaging materials, consumers in Denmark mix material and sustainability, exemplified by glass, which is perceived as sustainable, and plastics, which in general is seen as unsustainable. Consumers do not seem to consider (or seem to have no knowledge of) how products have been produced and transported. One environmentally relevant aspect, namely the weight of an empty packaging, appears to be completely ignored, since it is not addressed by any of the respondents. Instead, they show to base their idea of environmental sustainability on what they can do to recycle a packaging and on how much recyclable they perceive different materials to be. For this reason, glass scores high, and plastic is in general perceived negatively (even though some consumers who do recycle plastics perceive it more positively). This latter finding confirms the results obtained by Lindh et al. (2015), whose research showed that Swedish consumers regarded plastic-based packaging materials as

the ones with the greatest environmental impact. The way how the responding consumers assess sustainability, based on materials' recyclability and naturalness aligns well with the concept of Circular Economy which distinguishes between the technical and biological cycles (EMF, 2013). Materials in the biological cycle are meant to be returned to the soil by composting or anaerobic digestion, while materials in the technical cycle are designed to be recovered and upgraded (Braungart and Engelfried, 1992). Our findings also indicated that consumers have great faith in new packaging innovations made from natural materials, confirming previous results obtained in the so-called slow-moving and fast-moving consumer goods sectors (Petersen and Brockhaus, 2017). The empirical study on consumer research furthermore showed that consumers tend to think that bio-based materials are also biodegradable. Also the difference between 'compostable' and 'biodegradable' seems to be unclear for most consumers. This ambiguity is a challenge for the widespread use of both bio-based and biodegradable/compostable materials. Information to consumers is therefore needed, because the positive attitudes of the consumers really show the bigger opportunities in developing new types of compostable packaging where the lifetime of the packaging better matches that of the product, which is a generic way of not 'over-designing' the packaging.

Second, this research provides insights on the extent of knowledge of a specific category of consumers (well-educated, young urban Danish consumers) on a selection of environmental labels (RQ2). In the present study, the general knowledge of labels on environmentally sustainable packaging turned out to be quite low for most of the tested labels. Previous research on the impact of sustainability information (i.e. environmental, social, and health ratings of products and companies) on consumers´ online shopping behaviour showed that many consumers are unaffected by sustainability information (O'Rourke and Ringer, 2015). However, at the same time consumers who have expressed previous commitment to sustainability issues appear to make use of this information as part of their purchasing behaviour (O'Rourke and Ringer, 2015). As already identified by Hartikainen et al. (2014) in the case of carbon footprint labels, there is a clear need to educate consumers in order for them to i) understand better such labels as well as to ii) appreciate the potential to make environment- and climate-friendly choices by adjusting personal food consumption habits. Only a limited share of consumers involved in Hartikainen et al.'s research were aware that their food consumption represented the highest share the overall environmental impact of their consumption (Hartikainen et al., 2014). These findings are relevant in the context of large initiatives such as the Product Environmental Footprint (PEF) (EC, 2013), which among other purposes aims at testing different communication vehicles for the environmental performances of products, including labels. As demonstrated by Styles et al. (2012) in their review of European retailers´ performance, proactive retailers go beyond product labelling and use widespread product certification and extensive collaboration with suppliers to drive systematic environmental improvement across product groups associated with high environmental burdens.

Finally, the study contributes to the literature addressing the comparison between consumers´ perception of sustainability and LCA (RQ3). Our findings indeed confirm that consumers' perceptions are in some cases contrasting with LCA results for liquid food packaging such as beer and soft drink. This is aligned with the findings of Steenis et al. (2017), who in the case of tomato soups found that glass jars are perceived as very sustainable by consumers (ranked 2nd of 7 alternatives), but are actually least sustainable according to LCA. In the case of tomato soup, the bioplastic option was ranked as first in terms of sustainability by consumers, but caused a comparatively large environmental burden in LCA (ranked 5th of 7) (Steenis et al., 2017). Preferences towards bio-based packaging were shown to exist in the case of plastics in different

Western consumer cultures: Germany, France, and the U.S., but were not supported by LCA results (Herbes et al., 2018). Unfortunately in the present case, it was not possible to compare the perceived sustainability of bio-based solutions with the LCA results, but this kind of investigation is highly needed.

4.2 Practical implications

Packaging has been at the centre of discussions on sustainability for almost 50 years – and for good reasons, since packaging is such a central and visible aspect of human consumption. The Circular Economy both offers new directions and supports what is current practice in the packaging industry, in the sense that increasing recycling rate and recycled content can reduce the environmental impact of packaging solutions (Niero et al., 2016; Stotz et al., 2017). Denmark has a long and rich tradition of innovating policies that represent elements of Circular Economy, e.g. the introduction of the very first deposit-refund scheme for beverage containers in the 1980s. Even though Denmark is internationally recognized as a front runner society in terms of environmentally conscious behaviour, there are significant opportunities to further transition towards circularity, among others in the plastics and bio-based packaging sector, as well as in terms of reduction of waste production per capita (Ellen MacArthur Foundation, 2015). Yet, even with the high collection rates in Denmark there are still losses and challenges in keeping the materials at the same quality levels, and currently, the international recycling system is not truly circular, e.g. virgin aluminium needs to be added to can production (Niero and Olsen, 2016; Paraskevas et al., 2015; Stotz et al., 2017), and PET bottle recyclates are used for lower quality purposes than for new PET bottles (Grosso et al., 2017; Velis and Brunner, 2013). Moreover, the combination of collection type (supermarket, collection point or kerbside bag collection) and bottle type is a decisive factor for the environmental profile of a packaging option and should not be neglected. According to Simon et al. (2015), the one-way refund system of glass presents worse environmental impacts than the kerbside mixed bag collection of the same bottle type. There is a huge economic potential in improving recycling systems and in minimising the current loss of valuable materials from packaging. New international policies that create better incentives for recycling and reuse are needed. But this is not just a policy issue. The packaging and retail industries also have an important role to play. They have the responsibility to design packaging solutions that take the materials' next cycle into account from the outset, instead of just optimizing the path from company to consumer.

The findings of this research can guide packaging designers, purchasers and marketers to successfully design, purchase and market more sustainable liquid food packaging solutions. This can be done by providing solutions that are more sustainable and are also perceived as such by consumers – or by augmenting the consumers' perception through campaigns, so that the perceived sustainability is better aligned with solutions deemed more sustainable, based on scientific insight. Our results confirm the findings of Schäufele and Hamm (2017), who by performing a state of the art analysis in consumer perceptions towards wine with sustainability characteristics, concluded that actors in the food and beverage value chain, will likely profit from developing information campaigns with a focus on environmental aspects to increase consumers' knowledge of sustainable food and beverage production, thus creating preferences and influencing purchase behaviour.

Moreover, producers of food and beverage packaging should be aware of the importance of product-with-packaging interaction for innovation. The implementation of the cross-functional integration of actors into the packaging chain calls for specific research on the current dynamics and interrelation of interdisciplinary packaging design & marketing teams with a direct influence on packaging development (de Koeijer et al.,

2016). At the same time they should acknowledge, that end-users (e.g. consumers) often play a critical role with regard to sustainable innovation (Nielsen et al., 2016).

4.3 Implications for LCA of food packaging systems

The findings of the present research outline some challenges that need to be tackled in order to strengthen the usefulness of LCA as decision support tool for optimization of packaging systems. The importance of considering both consumer behaviour and packaging attributes when making packaging LCAs has been demonstrated (Wikstrom et al., 2016). Polizzi di Sorrentino et al. (2016) identified key areas in which LCA and ecodesign may benefit from integrating insights from behavioural science, namely measuring behaviour and assessing potential and means for changing behaviour. This is particularly relevant for packaging systems, where the environmental impacts are highly dependent on the EoL treatment, which in turn besides infrastructural conditions, highly depends on user behaviour. Due to a number of variables that affect the environmental burdens of different beverage packaging systems, it is indeed not possible to identify an overall "winner" material by conducting a general LCA for most materials (Simon et al., 2015). In order to provide a robust ranking of the environmental sustainability of packaging systems, it is therefore recommended to include the findings from consumer research in bespoke LCA studies. Investigation of the relationship between sustainable packaging and consumer behaviour has so far been limited, e.g. during the purchase and recycling stages of the packaging life cycle (Martinho et al., 2015).

The possibility to use packaging as a means to reduce or entirely prevent food waste incl. potential trade-offs needs to be investigated by means of LCA, as addressed by Wikström et al. (2014), who concluded that scenarios exploring the potential of packaging systems to reduce the overall environmental impact, i.e. the combined impact from the food and the packaging, through reducing food waste are desirable. The respondents of the present on-line survey were not directly asked how negative or positive they perceive packaging. However, in one of the statements of the survey (see section A.1 of the Supplementary Material), they were asked whether packaging is a bigger environmental problem than food waste, and few had a clear opinion on this or found the issues equally important. In the qualitative interviews the respondents were asked the same question, but no clear tendency could be derived from the answers. Out of the 10 people interviewed, 4 found that food waste was the biggest problem, 5 found packaging to be the worst and one was undecided. When asked directly, whether there was any link between the two issues, only a couple of people mentioned that packaging can prevent food waste. Consumers, who described packaging as the largest problem, argued that food waste might be expensive, but since food is degradable, it is not such a serious environmental issue. Some people expressed concern about micro plastic from packaging, and others just found that the largest problem with packaging is that it may end up in the wrong place. The reason why no clear conclusions can be drawn, compared to previous studies, can be due to the rising awareness of the environmental issue of food waste in Denmark in recent years. Even though concerns might increase in the future, the outcome from current research indicates that consumers only to a limited extent consider that packaging prevents food waste. Only 36% of respondents indicated that it is important that the packaging is formed in such a way that no product is wasted and only 3% stated the view that small portion sizes increase the environmental sustainability of the packaging. Further studies performing a consumer behaviour scenario analysis to evaluate variations in environmental impacts caused by the lifestyle and food consumption preferences of consumers are thus highly welcome (Yokokawa et al., 2018).

4.4 Limitations of the study and future research

The present study is limited in several ways. First, one key limitation lies in the limited size of the sample used for the online responses (n of around 200) and number of interviews (n=10), as well as the use of a convenience sample. However, studies on consumer perception with a similar size of sample have been used to compare consumer judgements and LCA results in the case of tomato soups in a Dutch context (Steenis et al., 2017) or to assess the influence on public perception of climate impact and on their importance for reducing the climate impact of food production and consumption in the German-speaking population of Switzerland (Shi et al., 2016). The sample used cannot be considered representative of the Danish population as a whole, but instead can represent well-educated, young urban Danish consumers. The reason for the misalignment against national average Danish population can be explained by the chosen distribution channels, which targeted young consumers, mainly undergraduate and graduate students. However, there are studies showing that caution should be used when attempting to extend any relationship found using e.g. college student subjects to a non-student (adult) population (Peterson, 2012). This emphasizes the importance of broadening the selection of interviewees by increasing population diversity and specifically addressing the influence of e.g. gender, age, country of origin, or environmental consciousness, before attempting any generalizations.

In terms of methodological shortcomings with regard to the consumer research, it should be noted that the order of presentation of product categories had not been randomized in the questionnaire, thus carry-over effects have not been regarded. The investigation of environmental sustainability perception may be broadened by means of different methods and theories from the field of consumer behaviour (Groening et al., 2017), such as the item response theory (Vincenzi et al., 2018), cue perception elicitation (Steenis et al., 2017), or signalling theory (Petersen and Brockhaus, 2017) and from the practice theory approach (Røpke, 2009). Moreover, the use of descriptive and correlation analyses could support the analysis of the results and identification of significant differences within the sample, as well as the testing of specific hypotheses (Li et al., 2017; Singh and Verma, 2018).

The limited size of the sample was counteracted by conducting dedicated streamlined LCAs and a literature review which, in combination, provided the framework for performing the comparison between the perception of environmental impact and scientifically assessed environmental impact in a comprehensive manner. However, a more systematic literature review or meta-analysis of LCAs in the food and beverage packaging sector could be performed in order to expand the temporal scope of the study. In the assessment of the potential environmental impacts we used GWP as a proxy, but further research should investigate how other impact categories relate to the perceived sustainability. Moreover, in order to compare the GWP scores among the modelled packaging options within the soft drink and beer categories and provide a ranking, the statistical variation of the scores should be investigated, e.g. by means of Monte Carlo analysis, which can be performed to propagate quantity uncertainty with LCA software tools and estimate the distribution of results (Igos et al., 2018). Future research could thus focus on improving the procedure for comparing LCA results with perception scores, e.g. by taking into account the distribution of the scores and providing correlations between consumer scores and LCA scores.

In terms of scope of the investigation on the knowledge of the meaning of sustainability-related eco-labels on packaging, only a limited set of eco-labels specifically addressing circular economy and recycling have been tested in the present study: a broader analysis distinguishing between different types of eco-labels is

recommendable, e.g. between ISO Types I such as the European eco-label and self-declared claims (ISO Type II), or between eco-labels in different regions, e.g. carbon footprint labels (Zhao et al., 2018), but also addressing different environmental impacts.

5 Conclusions

This explorative study aimed to contribute to filling the gap on the link between consumer research and LCA by investigating how – in the case of liquid food packaging – well-educated young Danish consumers perceive the environmental sustainability of such products, to what extent do they know about the meaning of eco-labels on packaging, and how their perception compares with what can be concluded from LCA studies.

The findings show that well-educated young urban consumers living in Denmark base the perception of the environmental sustainability of liquid food packaging on the material type and on what they can personally do at the end-of-life/disposal stage. Moreover, they seem to exclude life cycle based-considerations, i.e. the impacts related to packaging production and transport. Bio-material-based packaging types and glass packaging are perceived as the most sustainable options, plastic packaging as the least sustainable, meanwhile laminated cartons receive a mixed perception. The results from the LCA literature review showed that this might be problematic, since plastic and laminated cartons in comparison here show as environmentally most sustainable solutions, even though there are challenges related to their recycling. In addition, the streamlined LCA study for beer and soft drinks revealed that there is a considerable difference in environmental impact magnitudes (across impact categories) between glass being reused vs. one-way glass, but consumers do not seem to be aware of this difference. In the case of beer, there is a misalignment of consumers' perception score and GWP scores of PET bottles and aluminium cans compared to single use glass bottles. For soft drinks consumers seem to underestimate the environmental sustainability of plastic bottles compared to aluminium cans. In order to close the gap between what is perceived as environmentally sustainable packaging and what is scientifically assessed as such, improved information flows from the scientific field to consumers are recommended. As the consumers' knowledge on the meaning of a selection of environmental labels turned out to be limited, actions from all parts, including producers, retailers and policy makers are required. The final aim of such improvement efforts should be to provide consumers with the knowledge needed to make informed choices.

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